Negative electron-beam resist hard mask ion-beam etching process for the fabrication of nanoscale magnetic tunnel junctions

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MgO-based magnetic tunnel junctions (MTJs) with a large tunneling magneto resistance (TMR), where magnetic orientations can be controlled by spin-torque switching, are promising candidates for a non-volatile random access memory because of its high-speed operation, scalability and unlimited endurance.

To from MTJs, deposition and etch back technique is utilized employing a hard mask layer for pattern definition. Ta hard masks are generally used for reactive ion etching and ion beam etching (IBE) process due to relatively good selectivity over magnetic metals. However, tapering of the Ta mask is unavoidable which results in the underlying MTJ to become trapezoidal. This severely hampers the fabrication of sub-30 nm MTJs and also distorts the magnetic coupling between the pinned layer and the free layer.

Here we utilized negative electron-beam resist (NER) hard mask process to over come the hard mask induced nano-pattering difficulties. During the IBE process, redeposition of the etched material on the side walls of the NER protects the resis t from tapering, resulting in vertical side profiles in the etched MTJs. A low angl e IBE step is utilized to remove the side deposite after the vertical etch depth was reached using high angle IBE. Fig.1 shows the schematic diagram of the MTJ str uctures. Fig.2(a) shows the scanning electron microscope (SEM) image of the 30 nm NER hard mask array. Arrays of 30 nm dot patterns 200 nm apart were defin ed by electron beam lithography (NanoBeam, nB3) in AR-N 7520 (2-methoxy-1-methylethylacetate) with a thickness of 90 nm. IBE was performed at a beam sup ply voltage of 400 V and an accelerator supply voltage of 100 V. The IBE etch ra te of the NER used was ~ 3 nm/min at the given power and since the total MTJ et ching thickness was 36 nm with 2.1 nm/min etch rate, a 30 nm diameter NER pil lar with ~ 90 nm thickness was enough to produce the 30 nm MTJ nanopillars. Fi g.2(b) shows the SEM image of the 30 nm MTJ nanopillar after IBE. The 30 nm MTJ nanopillars had 1kΩ junction resistance and a 13 % MR ratio (Fig.3). This s howed that it may be possible to scale down the MTJ dimensions further by usin g the NER hard mask.

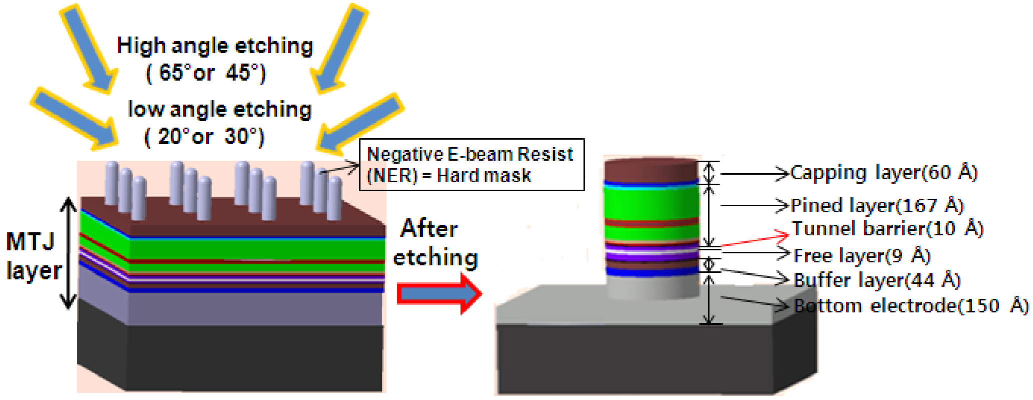

Fig.1. Schematic diagram of the etching process (left) and the fabricated MTJ nanopillar composition (right).

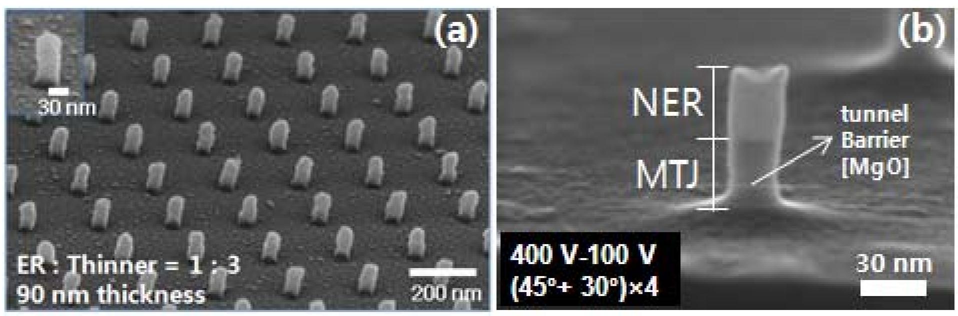

Fig.2. SEM image of (a) 30 nm diameter negative electron-beam resist (NER) hard mask array and (b) an MTJ pillar after IBE processing

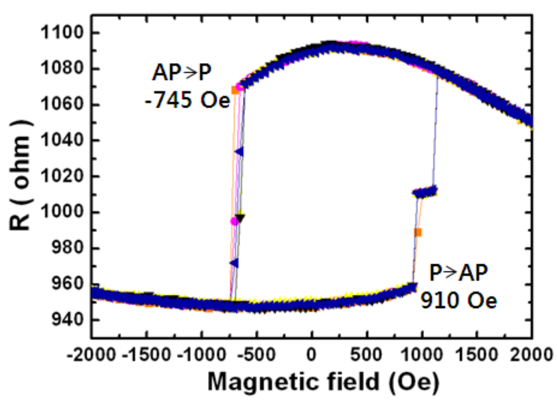

Fig.3. Perpendicular magnetic-field dependent resistance of the 30 nm diameter MTJ nanopillar measured at room temperature.